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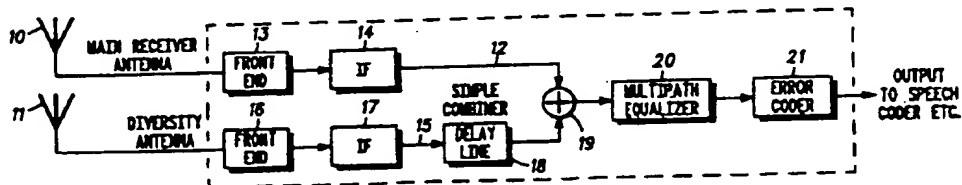


INTERNATIONAL APPLICATION PUBLISHED UNDER

WO 9608088A1

|   |    |   |
|---|----|---|
| (51) International Patent Classification 6:<br>H04B 7/02, 7/10, H04Q 7/38, 7/30, 7/20   | A1 | (11) International Publication Number: <b>WO 96/08088</b><br>(43) International Publication Date: 14 March 1996 (14.03.96)  |
| (21) International Application Number: PCT/US95/10046<br>(22) International Filing Date: 8 August 1995 (08.08.95)<br>(30) Priority Data: 08/304,102 9 September 1994 (09.09.94) US<br>(71) Applicant: MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US).<br>(72) Inventor: WATSON, Andrew, William, Drewry; Maricmont, 66A Ashley Road, Bathford, Bath BA1 7TS (GB).<br>(74) Agents: SONNENTAG, Richard, A. et al.; Motorola Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US). |    | (81) Designated States: AU, CA, FI, JP, KR, PL, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).<br><br>Published<br>With international search report. |

(54) Title: DIVERSITY RECEIVER WITH COMBINER FOR EQUALIZATION AND DIVERSITY TRANSMITTER WITH SPLITTER AND DELAY



(57) Abstract

A radio receiver is provided comprising at least a first antenna (10) and a second antenna (11) each having different directional antenna patterns; a variable delay (18) for delaying signals received at the antennas with respect to signals received at the other antennas; a combiner (19) for combining the signals received at each antenna and outputting a received signal; and an equalizer (20) for combining components of the received signal.

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DIVERSITY RECEIVER WITH COMBINER FOR EQUALIZATION AND DIVERSITY  
TRANSMITTER WITH SPLITTER AND DELAY

5

Field of the Invention

This invention concerns a radio receiver and transmitter  
antenna arrangement providing irregular coverage area. It is,  
10 specifically, applicable to radio transmission systems which use  
digital modulation and which incorporate equalizers for the  
reduction of multi-path propagation effects. An example of such a  
system is the GSM digital mobile radio telephone system. The  
invention also concerns a radio providing diversity reception and  
15 transmission.

Background to the Invention

Antenna diversity is a technique whereby two receiving  
20 antennas are used which are physically spaced apart by several  
wavelengths. The radio receiver conventionally has two separate  
parallel amplifying paths to which each antenna is connected.  
Towards the end of the receiver processing chain the two signals are  
fed into a processor which conventionally either selects the best  
25 signal or phase shifts and then coherently adds the two signals. The  
purpose is that for fading signals (e.g. for mobile radio systems), the  
signals on the two antennas are statistically much less likely to be in  
a faded condition simultaneously. Thus the diversity combined  
signal will exhibit reduced fading effects. The conventional double  
30 receiver and diversity combiner add significant extra complexity,  
however, and it would be desirable to provide a simpler solution.

For digitally modulated radio systems incorporating multi-  
path equalizers (e.g. GSM), European Patent Application publication  
No. 0430481 describes a diversity arrangement in which each of  
35 two parallel receiver chains is connected to one of two ports of a  
special two-port equalizer, which acts as an integrated

equalizer/diversity combiner. The arrangement nevertheless it still requires a double receiver chain.

British Patent Application publication No. 2237706 describes a space-diversity system in which signals to or from one antenna are delayed with respect to signals to or from a second antenna and a Viterbi equalizer is used to combine the delayed and undelayed signals.

A problem with prior art arrangements is that circumstances could be such that the delay of the delay element is, at least occasionally, virtually equal to the actual multi-path separation for different propagation paths, thereby making reception worse rather than better.

Radio transmitting and receiving stations provide coverage of their signals in their intended area of service. An example is the cell sites used to provide service coverage for cellular mobile radio telephone systems.

The desired area of coverage is determined by the radiated power of the transmitting system, the sensitivity of the receiving system, the shape of the antenna radiation patterns, the direction and height of the installed antennas, as well as intervening terrain between the cell site and the subscriber to the radio service. (e.g. the mobile or portable station for the subscriber of a cellular mobile telephone system). Cellular mobile telephone systems usually operate under interference conditions and therefore the effective boundary of the cell (best server) is determined in a complex way by the coverage of the interfering cells and the neighbour cells.

Cell site antennas can employ omni-directional antennas or directional antennas. Over flat, even terrain and in the absence of interference, the shape of the coverage area will largely follow the radiation pattern of the antenna. This will normally be a regular symmetrical shape.

It is sometimes desirable to achieve irregular coverage, for example to follow a particular terrain or boundary feature. This would require a cell site antenna with an irregular pattern.

Conversely however, very often, terrain features will modify the coverage of a cell site antenna, compared to the coverage that it

would have over regular terrain. The result of such modified coverage may be poor service in some areas and interference to subscribers using a different cell in other areas. Thus, it is desirable to compensate for the effect of modified coverage by means of an antenna with a compensatory irregular radiation pattern.

It is very difficult to design a single antenna having a complex irregular radiation pattern. Furthermore, it would be prohibitively costly to tailor the design of antennas to particular cell sites.

Antennas with complex and irregular radiation patterns can be made by means of the phased array antenna technique. However, such antennas are costly, difficult to set up to the desired pattern, sensitive, delicate, require regular maintenance and are usually large.

Simple combination of multiple antennas with different radiation patterns in order to produce a combined pattern of the desired shape have not been successful. Simple combination (i.e. additions) of the signals from multiple antennas causes severe interference lobes, particularly at the boundary between the patterns of the individual antennas.

A method of combination is desired that overcomes the problem and provides reliable irregular shaped coverage areas.

#### Summary of the Invention

In accordance with a first aspect of the present invention, a radio receiver is provided comprising first and second antennas, physically spaced apart to provide diversity, and an equalizer for combining components of a received symbol which are separated in time, a combiner for combining the signals received at the first and second antennas and coupling the combined signal to the equalizer and a variable delay means in the receive path of one of the antennas, for delaying signals received at that antenna with respect to signals received at the other antenna, so as to significantly reduce the probability of destructive interference between the signals from the first and second antennas.

In accordance with a second aspect of the invention, a corresponding transmitter is provided as defined in the claims.

In accordance with a third aspect of the invention, a radio receiver is provided comprising first and second antennas each having different directional antenna patterns; a variable delay means for delaying signals received at the antennas with respect to signals received at the other antennas; a combiner for combining the signals received at each antenna and outputting a received signal; and an equalizer for combining components of the received signal.

In accordance with a fourth aspect of the invention, a corresponding transmitter is provided as defined in the claims.

The invention in all its aspects provides a very cheap and simple arrangement in which diversity and irregular coverage can be provided. A particular advantage is that diversity can be provided by simply adding a combiner, a delay element and an extra antenna, for example in the RF stage. No additional processing is essential, because the signals from the two antennas are additionally combined by the equalizer operating in its normal manner.

Two antenna signals may be processed by (different) delay line means or a plurality of antenna and delay lines may be used. A phased array can be provided comprising parallel receiver chains for diversity and combinations of delay elements in one or more of the receiver chains for further diversity.

Multi-path diversity can be provided through more than two antennas, provided that the signals from the antennas are separated from each other by a delay.

The delay means may be analog or digital and may exist in the IF or RF stages. In the case of RF processing, the delay means can be in the form of an external unit which may incorporate its own frequency converters, IF amplifiers and delay means.

The delayed and added signal may be enabled, disabled or modified according to some detected characteristic of the signal, as is described below.

The problem addressed by the invention also arises in a repeater or cell enhancer which incorporates a delay, where the delay in a signal from the repeater can, at least occasionally, virtually equal the actual multi-path delay separation for signals from the repeated an a main cell transmitter, thereby making reception worse rather than better.

### Brief Description of the Drawings

Figure 1 shows a first embodiment of a multi-path enhancement  
5 diversity receiver in accordance with the invention.

Figure 2 shows a phasor diagram for explanation of the invention.

Figure 3 shows an embodiment of a diversity receiver in  
accordance with the invention, in which the delay means are provided  
in the RF stage.

10 Figure 4 shows an add-on RF diversity unit in accordance with  
another embodiment of the invention.

Figure 5 shows a transmitter providing diversity in accordance  
with aspects of the invention.

Figure 6 illustrates a repeater employing the invention.

15 Figure 7 shows the repeater of Figure 6.

Figures 8 ,9 and 10 show radiation patterns of antennas.

Figure 11 shows a receiver in accordance with an embodiment of  
the present invention.

20 Figure 12 shows a transmitter in accordance with an embodiment  
of the present invention.

### Detailed description of the preferred embodiments

Referring to Figure 1, there is shown a part of a typical GSM radio  
receiver comprising a main receive antenna 10 and a diversity antenna  
25 11. The main antenna 10 provides a signal to a main receive path 12  
comprising a front end RF amplifier unit 13 including a frequency  
converter unit (not shown) and an IF stage 14. A number of frequency  
converter units and IF stages may be used. The diversity antenna  
provides a signal to a diversity receive path 15 comprising a front end  
30 amplifier unit 16 and an IF stage 17. The diversity receive path 15  
also comprises a delay element 18 which may be in the form of a long  
transmission line, surface acoustic wave delay line, or one or more  
filters. The output of the IF stage 14 on the main receive path 12 and  
the delay element 18 on the diversity receive path are combined in a  
35 simple combiner 19 and passed to a multi-path equalizer 20. The  
multi-path equalizer is in accordance with the GSM specification and

may, for example, be that described in EP-A-0318685 or EP-A-0343189. The equalizer 20 is in digital form, i.e. the input to the equalizer 20 is an A/D converter. The equalizer uses four-times oversampling. After equalizing, the signal is subjected to error coding in an error coder 21, in accordance with the GSM specification, and the result is passed to a speech decoder for extracting speech information and synthesizing speech. Analog equalizers could equally be used.

The operation of the receiver of Figure 1 is as follows. A GMSK signal (or other binary modulated signal) is received at an antenna 10 from a mobile transmitter. At the same time, a signal is received from the transmitter at antenna 11 via a different path. Each symbol of the signal has a duration of approximately 4 microseconds. The signals received at the antennas are amplified and down-converted in front end units 13 and 16 and IF stages 14 and 17 respectively. The signal from antenna 11 is delayed in delay element 18. The delay element delays the signal by at least a sufficient fraction of a bit period that when combined in the combiner 19, the probability of destructive interference between the signals from the paths 12 and 15 is significantly reduced. In order to further reduce the probability of destructive interference, the delay introduced by the delay element is made variable. The combiner 19 sums the signals and passes the summed combination to the multi-path equalizer 20. The equalizer 20 performs digital-to-analog conversion and applies appropriate delays and phase shifts to different portions of the signal so as to realign the various components of a symbol in time and phase, in a manner known in the art in respect of inter-symbol interference equalization. The equalizer 20 acts on the separate components of the signal received on paths 12 and 15 (and any components introduced by actual multipath reflections before reaching the antennas 10 and 11) and corrects the time error and any phase error therebetween. The resultant equalized signal is demodulated to extract the symbols and subjected to error coding in the error coder 21.

To reduce the probability of destructive interference at the combiner 19, a delay of at least  $1/4$  bit period is preferred (though smaller delays may suffice). A  $1/2$  bit period is considered a useful delay. A limiting factor is the bandwidth of the filters in the signal

path after the combiner. In the GSM system, these filters will remove the distinction between two signals separated by less than about one bit period. Accordingly, a particularly preferred delay is in the 1 to 2 bit-period range. The GSM equalizer is typically designed to equalize  
5 delays of up to 16 microseconds and in theory a delay of 10-16 microseconds can be used (i.e. up to 5 bit periods), but some benefit will be lost if the signals themselves are subject to multi-path delay. Use of greater oversampling in the equalizer may permit shorter delays

10 The principle of operation of the equalizer 20 is further illustrated with reference to Figure 2. The figure shows a time axis with phasors representing multiple signals illustrated rotating in phase around the time axis. The time axis is shown in stereoscopic view so that both the time delays and the phases of the different phasors can  
15 be seen. Two symbols Q1 and Q2 are illustrated separated in phase. If these symbols were to be summed, they would provide the result  $Q1 + Q2$  illustrated. It can be seen that these symbols can either be summed together or can cancel each other out with equal likelihood. In contrast, the symbols Q3 and Q4 are illustrated which have been  
20 separated in time by delay d. When summing these in summer 19, being wide-band signals, they cannot cancel each other out. The equalizer performs a phase shift on symbol Q4, bringing it into phase with symbol Q3 and delays symbol Q4 so that it coincides with symbol Q3. Thus the two symbols are added and will always provide a larger  
25 resultant signal illustrated as Q3 and Q4.

The principle is that the multi-path equalizer will coherently combine two or more signals of any phase which arrive at a receiver antenna, provided that they exhibit a different time delay. This is the normal intended function of the equalizer in enhancing signals which  
30 suffer multi-path propagation. In this application, the diversity signal is made to look like a multi-path delayed signal by the added delay line and it is, therefore, coherently combined by the conventional multi-path equalizer. The delay is made variable in order to remove the possibility that the deliberately introduced delay is equal but  
35 opposite to the natural propagation delay of the signal between the two antennas. No additional phase correction is required and provided the

equalizer has been optimized, the diversity improvement could be a minimum of 3 dB and typically 6 dB for fading signals. The delay line means could be an analog delay line, a digital delay line, an IF delay line or an RF delay line (see below). Transmission line, lumped circuit, surface acoustic wave or digital circuitry can be used (not necessarily exclusively) for the delay line.

In a linear receiver, such as used for the GSM mobile telephone system, the delay line and simple combiner can be implemented at the front end of the RF section of the receiver. This is illustrated in Figure 3. In this figure, elements of Figure 3 have the same reference numerals as in Figure 1. An RF delay line 25 is connected to the diversity antenna 11 and the other end of the delay line is connected to a simple RF combiner 26, together with an RF connector from the main antenna 10. The output of the combiner 26 is passed to the front end unit 13 and other elements as shown. The arrangement is possible because two or more independent signals can be processed by a linear receiver without mutual interference. This means that the double receiver chain can be dispensed with. A conventional non-diversity receiver (with equalizer) can be used with the diversity components (delay line means and simple combiner) contained within a external, add-on unit.

The combiner can be a simple signal adder or a hybrid. The delay line can operate at RF frequencies, or the RF diversity unit can incorporate its own frequency converters so that the delay line can operate at an intermediate frequency, as illustrated in Figure 4.

Referring to Figure 4, elements of Figure 3 are shown with the same reference numerals. Between the diversity antenna 11 and the combiner 26 are provided a first RF filter 30, a mixer 31, an IF filter 32, a delay element 33, a second mixer 34 and a second RF filter 35. Coupled with the mixers 31 and 34 is a local oscillator 36. The mixer 31 and generator 36 operate to down-convert the signal to an IF frequency such as 100-200MHz. At such a frequency, a cheap and compact delay element 33 can be implemented, for example in the form of a surface acoustic wave filter. The IF frequency is up-converted in mixer 34 and the operation of the invention is as for the Figure 3 embodiment.

Items 11, 25 and 26 could be supplied as an add-on unit.

Under certain conditions, when one or more of the diversity signals suffers actual multi-path propagation, it will be advantageous to alter the time delay of the delay line for each frame of the digitally modulated signal. This is achieved by using switchable delay elements, for example as shown in dotted outline in Figure 4, where delay element 40 has a longer delay than that of element 33 and is switchable into the IF path in place of element 33. Alternatively, in the embodiment of Figure 3, the delay element 25 could be switched from the diversity receive path to the main receive path - i.e. between points A-A' and B-B'. Combinations of these arrangements could be used.

The switching of the delay element is in response to dispersion information taken from the equalizer 20. As an alternative, the switching is repetitive or pseudo-random.

In a further embodiment of the invention, a small frequency shift of about 3 to 5 kHz is applied to the diversity signal and/or a phase shift of 0-360° is applied. This feature provides improvements when the signals are Doppler shifted. In the embodiments of Figures 1 and 4, the frequency shift is applied in the IF stage, for example by adjusting the injection frequency from oscillator 36. The frequency shift can be made at the RF level in a manner readily implemented by one skilled in the art. A phase shift is implemented by a variable capacitor/diode network in the RF signal path, or by a series of transmission line phase shift elements. This technique of switching the delay element operates in conjunction with the error coder 21 in a manner similar to the principal of frequency hopping in the GSM art.

As for the switching of the delay element, the frequency shift and/or phase shift is varied on a frame-by-frame basis.

The delay, frequency shift and/or phase shift can be enabled, disabled or modified according to characteristics of the received signal such as signal strength, interference or delay spread. In this way, an adaptive multi-path enhancement diversity arrangement is provided.

In principle, multi-path enhancement diversity could be used at the receivers at either end of a two-way radio link. For mobile/portable radio telephone systems, it is rarely attractive to have

a second antenna system on the mobile or portable unit (i.e. diversity for the downlink path - base-to-mobile path).

Figure 5 illustrates an arrangement in accordance with another aspect of the invention in which a delay element is introduced within the transmitter chain enabling the use of two transmitting antennas at the base station to provide downlink diversity, instead of two receiving antennas on the mobile or portable unit.

The arrangement comprises a transmitter 50, a simple splitter 51, a main transmitter antenna 52, a diversity transmitter antenna 53 and a delay element 54 connected between the splitter 51 and the diversity antenna 53. The transmitter 50 communicates with a mobile unit 55 which incorporates a multi-path equalizer. The additional features of delay switching, frequency shifting and/or phase shifting described above can also be applied. In practice, the delay element 54 is preferably included in the transmit path prior to power amplification of the signal and two power amplifiers are provided for amplifying the primary signal and the delayed signal.

The transmitter 50 can be a transmitter only and the mobile unit 55 can be a receiver only, provided with a multi-path equalizer specifically added for the task of equalizing the signals from the main and diversity antennas 52 and 53.

The principal of the invention can be applied to a cell enhancer to overcome problems at the boundary of the cell enhancer arising from natural multiple paths (from the main cell and the enhancer). This is illustrated in Figure 6, in which a main cell transmitter 60 is shown having a transmit radius 61 and, within the main cell transmit radius there is a cell enhancer 62 having a transmit radius 63. The cell enhancer is typically used to cover a problematic area or "hole" in the cell. It has a transmit radius smaller than that of the main cell. The cell enhancer simply retransmits the signal 65 it receives from the main cell transmitter, with shielding provided to prevent it from retransmitting its own signal. At a point 64 on the boundary of the cell enhancer transmit area, the signal 66 from the cell enhancer may arrive almost simultaneously with the signal 67 from the main cell transmitter. In accordance with this aspect of the invention, the cell enhancer introduces a delay in the signal 66. This delay is periodically

switched in order to accomodate possible fading at different points on the cell enhancer transmit boundary.

As shown in Figure 7, the cell enhancer 62 comprises a receive antenna 70, a transmit antenna 75 and a receive/transmit path comprising preamplifier 72 and power amplifier 74. A delay element is introduced on the receive side at position 71 or before the power amplifier at position 73. The delay is switched frame-by-frame by timing circuitry 76. It will be understood that variations described above in relation to receive diversity and transmit diversity can be implemented. For example there can be more than one receive antenna or more than one transmit antenna. In each case the signal through one antenna is delayed with respect to the signal through the other(s).

A further aspect of the present invention provides the means by which two or more antennas may be combined to produce a complex radiation pattern which is the superposition of the simpler radiation patterns of the individual antennas. Thus, irregular coverage may be achieved in order to follow a particular terrain or boundary feature. This is done according to the present invention without causing the interference lobes which would result from simple additive combination. It is applicable to radio systems which use digital modulation and which incorporate equalisers for the reduction of multi-path propagation effects.

In practice, when terrain features modify the coverage of a cell site antenna, compared to the coverage that it would have over regular terrain, the present invention may be used to compensate for the effect by means of an antenna with a compensatory irregular radiation pattern. This situation is shown in Figures 8 and 9. In Figure 8, line 83 represents the pattern of an omni-directional antenna 81 and the coverage it would provide over flat, even terrain. However in direction x, the coverage is reduced due to hilly terrain in that direction. In direction y, coverage is extended due to ducting along a valley. In direction z, coverage is as expected, over regular terrain. The overall irregular coverage boundary is shown as line 84 in Figure 8.

The reduced coverage in direction x provides poor service quality for users in that area, while the extended radiation in direction y is undesirable because it could cause interference to subscribers using a distant cell which shares the same frequencies.

5 In order to compensate, an antenna with the inverse irregular radiation pattern is required, as shown in Figure 2. Such an antenna arrangement may be provided according to the present invention so that increased radiation is provided in direction X and reduced radiation is provided in direction Y. The overall radiation pattern  
10 (i.e. measured over flat terrain or in a test chamber) would need to approximate to line 91 in Figure 9.

An antenna arrangement, according to the present invention, produces the desired effect of such a combination process is shown in Figure 10, whereby three antennas with individual patterns  
15 shown by lines 104, 105 and 106 combine to produce an overall radiation pattern shown by line 107. This approximates to the required irregular pattern required by the example shown in Figure 9.

An antenna arrangement, according to the above aspect of the present invention is shown in Figure 11. A radio receiver 111 is  
20 provided including two or more antennas 112-114 each having different directional antenna patterns, an equaliser 116 for combining components of a received signal, a combiner 118 is provided for combining the signals received at each of the antennas  
25 and coupling the combined signal to the equaliser 116 and separate delay means 121-122 are provided in the receive path of each of the antennas for delaying signals at that antenna differently with respect of signals received at the other antennas so as to eliminate the probability of interference between the signals from the  
30 different antennas.

In accordance with a further aspect of the invention, as shown in Figure 12, a radio transmitter 200 is provided for communication with a receiver 201 having an equaliser 202 for combining  
35 components of a received symbol which are separated in time wherein that the transmitter comprises two or more antennas having different directional antennas. Splitter means 209 for

splitting the signal to be transmitted and coupling it to the different antennas 203-205 and delay means 206-208 provided in the transmit path of each of the antennas for delaying the signals transmitted by that antenna by more than the pre-determined minimum delay with respect to signals transmitted by any of the other antennas so as to eliminate the probability of interference between the signals from the different antennas.

The present invention provides a cheap and simple method in which multiple antenna sets (transmit and receive) can be combined without mutual interference in order to provide irregular cell site coverage or alternatively to compensate for the irregular cell site coverage which would otherwise occur for a single antenna set due to terrain features. A particular advantage is that the irregular cell coverage, so produced, is a single cell rather than separate cells, as would be the case if separate transmitter/receivers operating on different frequencies were connected to each antenna. The arrangement described herein is much simpler in terms of equipment and the requirement for control channels than the alternative of a site having separate multiple cells.

According to the present invention, the shape and amplitude of the individual antenna patterns required to make up the pattern of the combined cell site coverage of the irregular cell sites may be controlled by many factors. These include:-

- 1 The horizontal beam width of the individual antennas;
- 2 The gain of the individual antennas;
- 3 The direction of pointing of each antenna;
- 4 The height of each antenna;
- 5 The down tilt of each antenna.

Path loss prediction programs exist to determine the coverage pattern of the individual antennas for the actual terrain area over which they radiate (taking into account terrain features, free space antenna pattern, antenna height and down tilt etc.) Such programmes can be used to determine the combined coverage for the actual terrain.

The method of operation of the antenna combining scheme is as described above with reference to Figures 1-7. The difference in embodiments is that in the case of combining two (or more) antennas to provide diversity reception, the antennas would  
5 normally have the same radiation patterns and direction of radiation but, are spaced apart by at least several wavelengths. In the present invention, the antennas have different radiation patterns and/or different directions of radiation in order to produce an irregular radiation pattern when combined and the individual  
10 antennas may or may not be co-located.

In both embodiments, for a cellular mobile telephone system, normally both transmitter combining and receiver combining would be used at a site. The antenna arrangements may be used  
15 particularly in either TDMA or CDMA communications systems.

Claims

1. A radio receiver comprising:  
at least a first antenna and a second antenna each having  
different directional antenna patterns;  
5 a variable delay means for delaying signals received at each  
antenna with respect to signals received at the other antennas;  
a combiner for combining the signals received at each antenna  
and outputting a received signal; and  
an equalizer for combining components of the received signal.  
10
2. A radio receiver according to claim 1 wherein the signals  
received at the antennas are divided into discrete frames and the  
delay means vary the delay from frame to frame.
- 15 3. A radio receiver according to any one of the preceding claims  
wherein the delay means further comprises frequency shift means for  
shifting the frequency of the signal received at one antenna with  
respect to the frequency of the signal received at the other antenna.
- 20 4. A radio receiver according to any one of the preceding claims  
wherein the delay means further comprises phase shift means for  
shifting the phase of the signal received at one antenna with respect  
to the phase of the signal received at the other antenna.
- 25 5. A radio transmitter for communication with a receiver having an  
equaliser for combining components of a received symbol which are  
separated in time, the transmitter comprising:  
a plurality of antennas each having different directional antenna  
patterns to provide a desired combined antenna pattern;  
30 splitter means for splitting a signal to be transmitted and  
coupling it to each of the antennas; and  
delay means provided in the transmit path of each of the  
antennas for delaying signals transmitted by that antenna by more  
than the pre-determined minimum delay with respect to signals  
35 transmitted by the other antennas so as to significantly reduce the

probability of destructive interference between the signals from the different antennas.

- 5 6. A radio receiver comprising:  
at least a first antenna and a second antennas physically spaced  
apart to provide diversity;  
variable delay means in the receive path of each of the antennas  
for delaying signals received at that antenna with respect to signals  
received at the other antenna;  
10 a combiner for combining the signals received at each antenna  
and and outputting a combined signal;  
an equalizer for combining components of the combined signal  
which are separated in time.
- 15 7. A radio receiver according to claim 6 further comprising means  
for receiving signals at each antenna which is divided into discrete  
frames and means for varying the delay is from frame to frame.
- 20 8. A radio receiver according to claim 7, wherein the equalizer  
comprises means for indicating a characteristic of the combined signal  
and the means for varying the delay varies the delay in response to  
the characteristic.
- 25 9. A radio receiver according to claim 8 wherein the characteristic  
is the dispersion of the combined signal.
- 30 10. A radio transmitter for communication with a receiver having an  
equalizer for combining components of a received symbol which are  
separated in time, the transmitter comprising at least a first antenna  
and a second antenna physically spaced apart to provide diversity,  
splitter means for splitting a signal to be transmitted and coupling it  
each antenna and a variable delay means provided in the transmit  
path of at least one of the antennas for delaying signals transmitted  
by that antenna by more than a predetermined minimum delay with  
35 respect to signals transmitted by the other antennas.

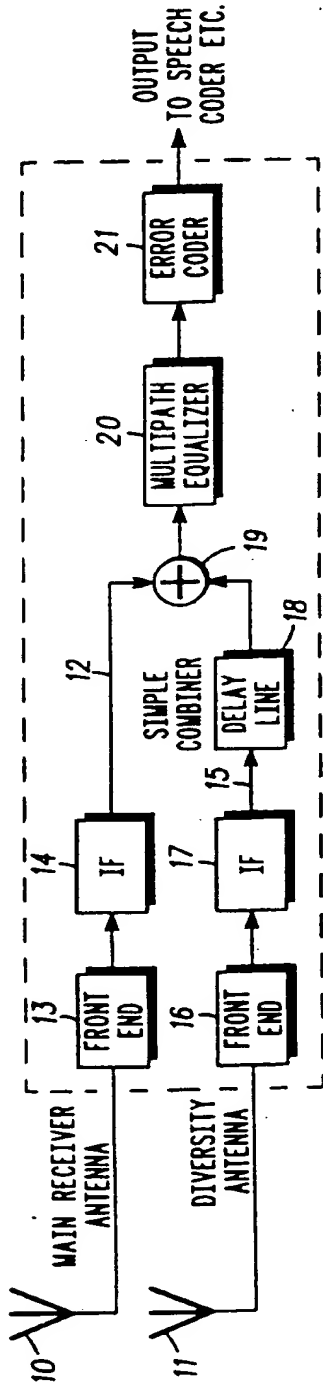


FIG. 1

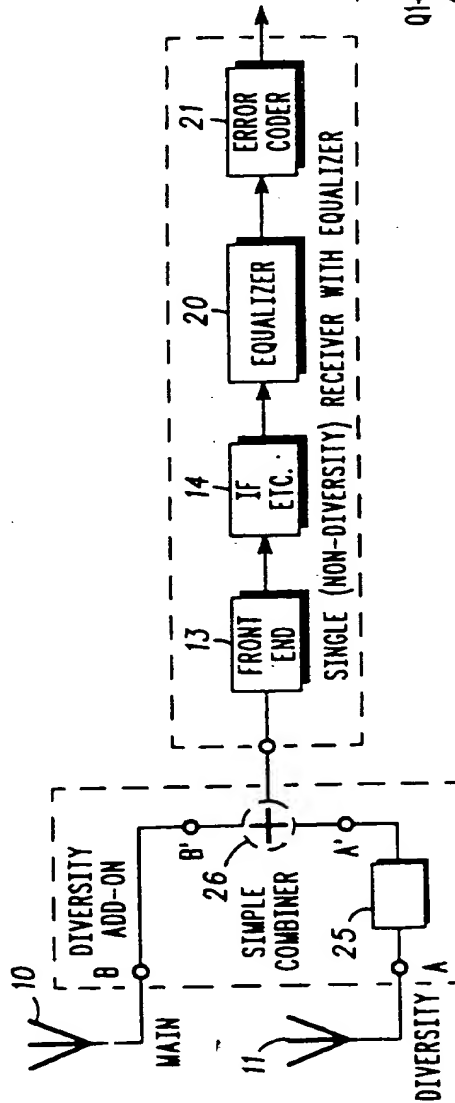


FIG. 3

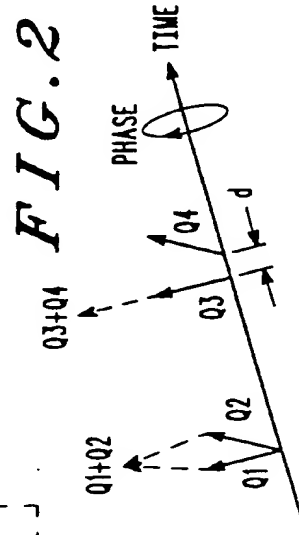


FIG. 2

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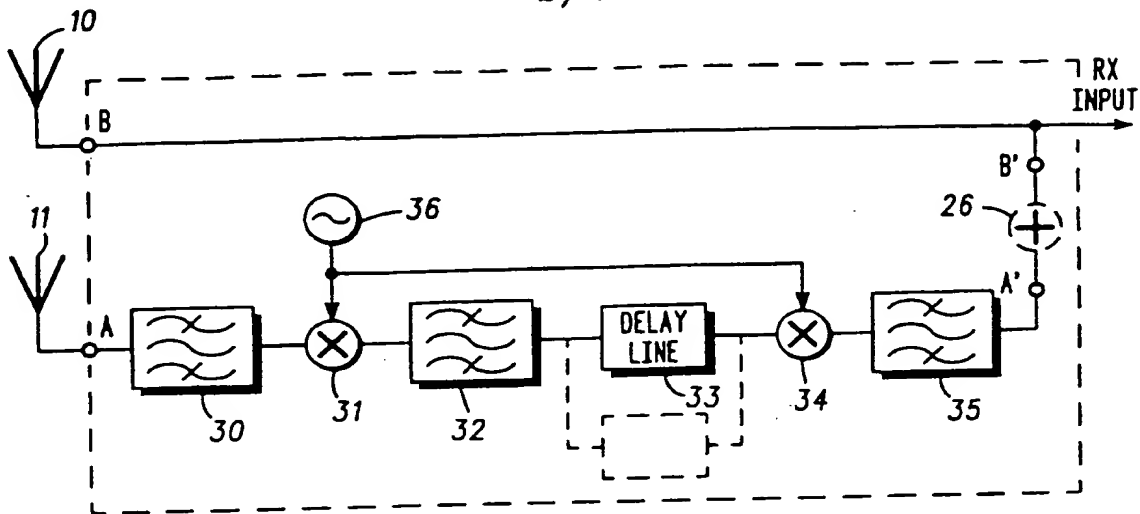


FIG. 4

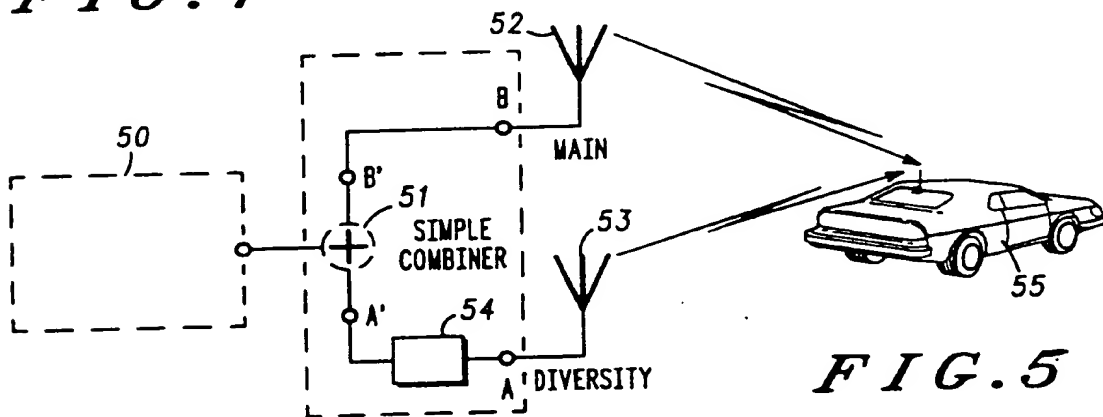


FIG. 5

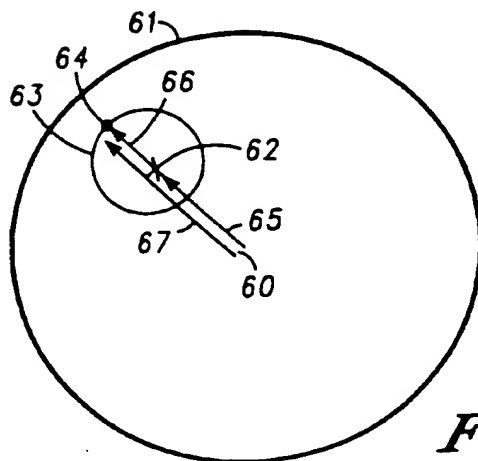


FIG. 6

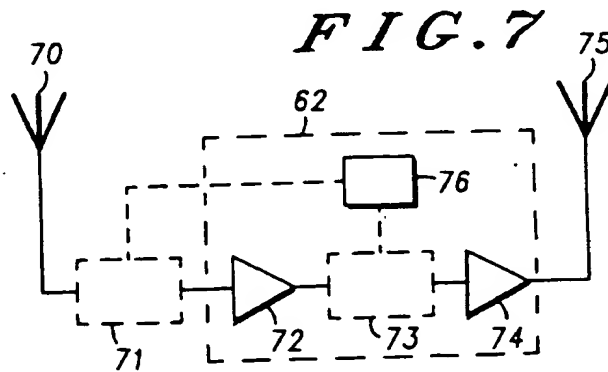
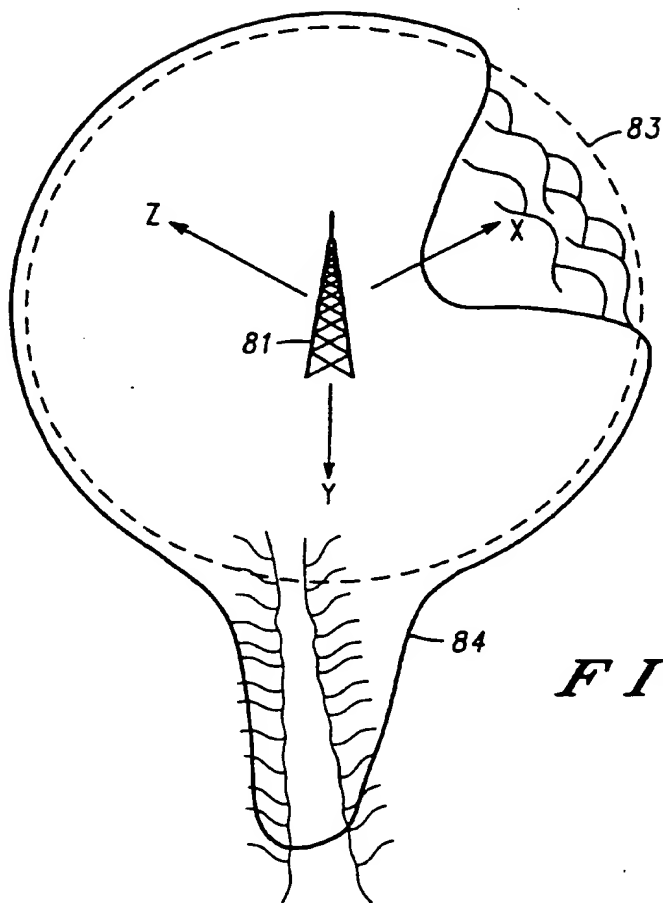
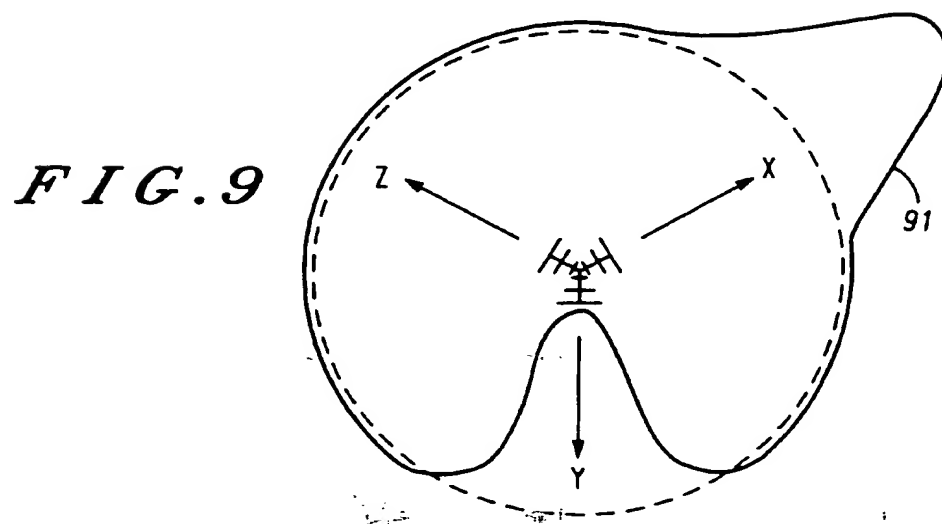


FIG. 7

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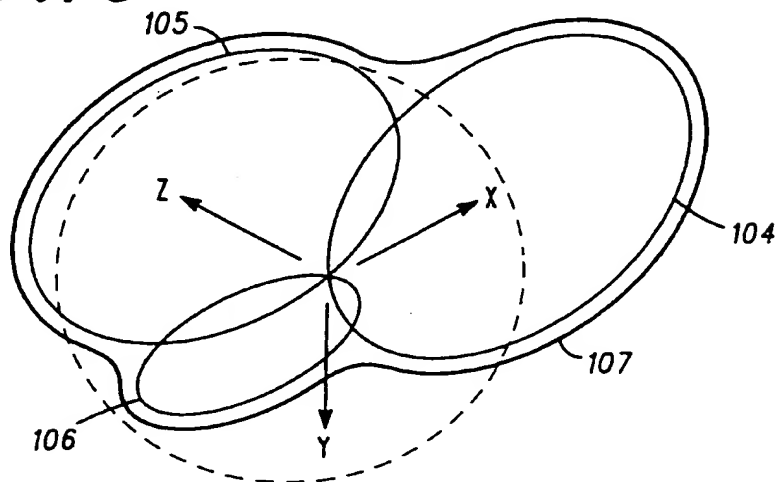
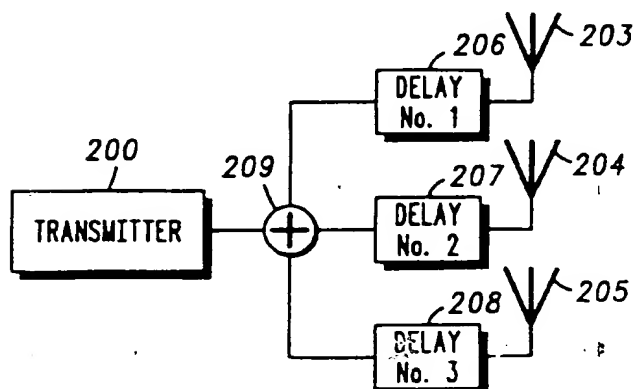
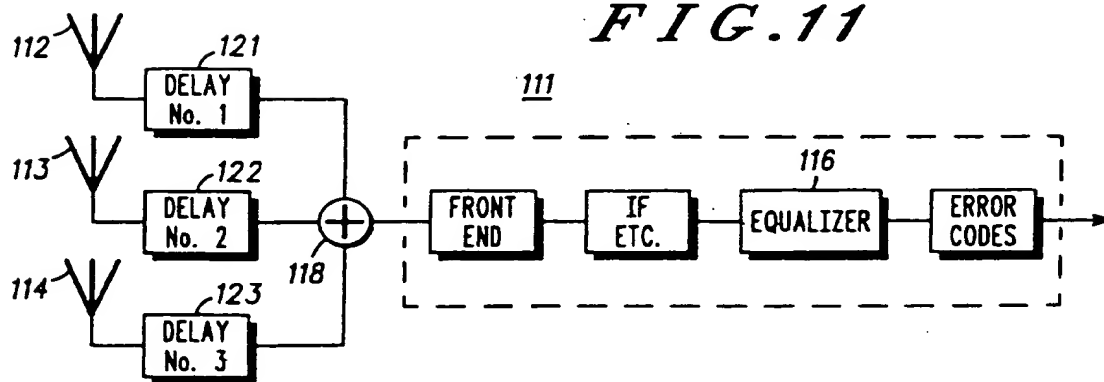
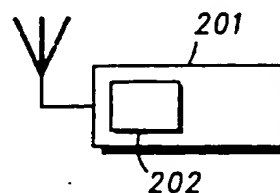
**FIG. 8**



**FIG. 9**

**FIG. 10**

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**FIG. 11****FIG. 12**

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/10046

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04B 7/02, 7/10; H04Q 7/38, 7/30, 7/20

US CL : 375/267, 299, 347; 455/33.1

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/267, 299, 347; 455/33.1, 101

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                 | Relevant to claim No. |
|-----------|--|-----------------------|
| Y         | GB, A, 2,237,706 (GARDNER) 05 August 1991, Figure 4 items 10, 20, 22, 36, 38, 40, pg 6 lines 7-10. | 1,5-6,8-10            |
| Y         | US, A, 4,278,978 (EASTERLING ET AL) 14 July 1981, Figure 1, Figure 4 item 46.                      | 1,3,5-6,10            |
| Y         | US, A, 4,354,276 (KARABINIS) 12 October 1982, col. 2 lines 6-10, Figure 1 item 17.                 | 1,4-6,10              |
| Y         | US, A, 4,852,090 (BORTH) 25 July 1989, abstract.   | 8-9                   |
| Y         | US, A, 5,031,193 (ATKINSON ET AL) 09 July 1995, abstract.  | 8-9                   |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

11 SEPTEMBER 1995

Date of mailing of the international search report

05 OCT 1995

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Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

WILLIAM LUTHER

Telephone No. (703) 308-6609